Characterizing Planets

Mark Marley
NASA Ames Research Center

Why Characterize Planets?

- Giants
- Terrestrials - Carl Pilcher

Giant Planets are **not** Interesting

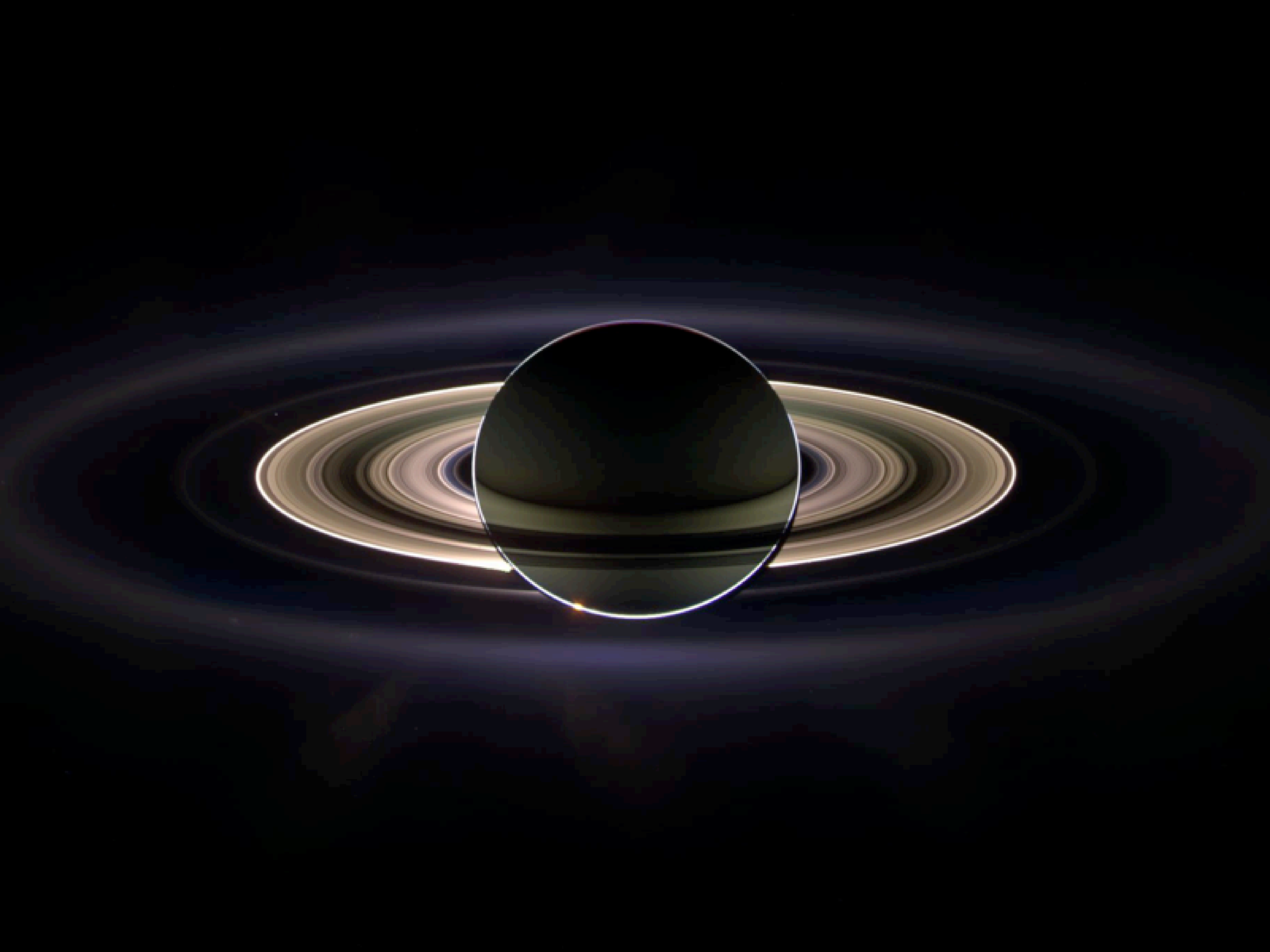
- Radial velocity & SIM will determine masses and orbits
- Giants are not interesting for astrobiology
- Giant planet science provides no heritage for terrestrial planet characterization and is a “niche” field
- Small, giant planet-focused missions are not interesting, not on the critical path to detecting Earths, and are ***not worth flying***

Giant Planets **are** Interesting

- Radial velocity & SIM will determine masses and orbits: *Planets are more than masses on springs and well characterized planets are fiducials for more distant or younger objects which may lack RV/astrometric masses*
- Giants are not interesting for astrobiology: *they provide a record of stellar system formation & perhaps volatile transport*
- Giant planet science provides no heritage for terrestrial planet characterization: *provide end to end experience of planet characterization, heritage for bigger efforts*

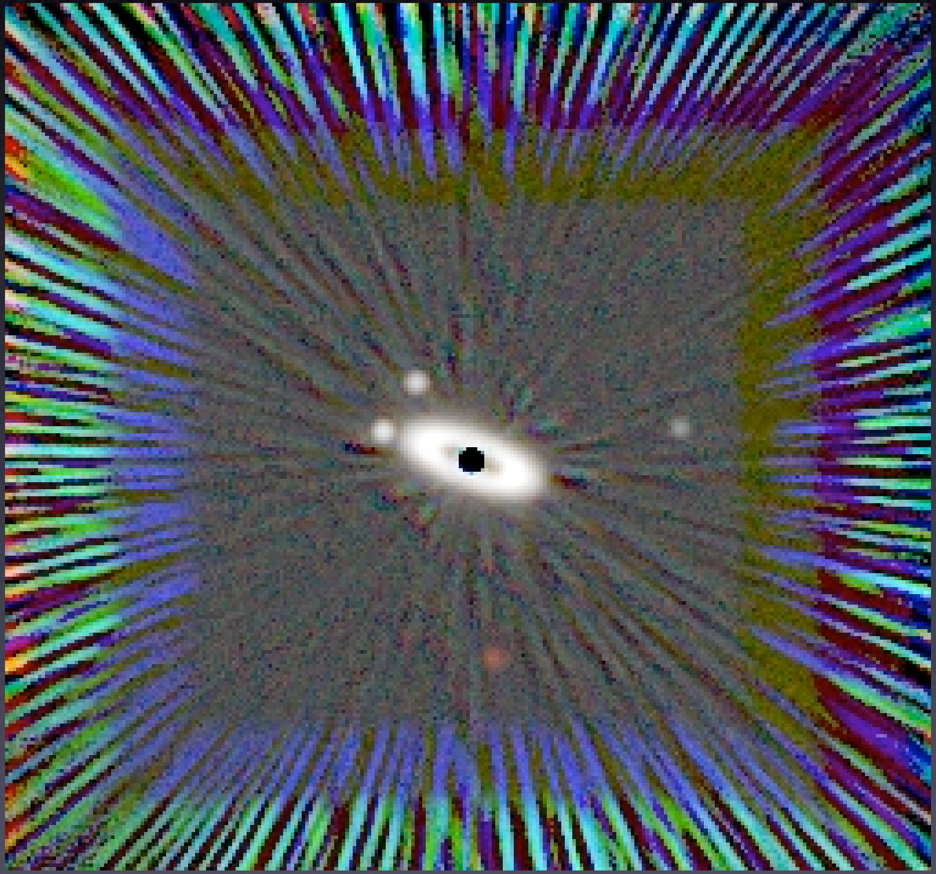
Giant Planets **are** Interesting

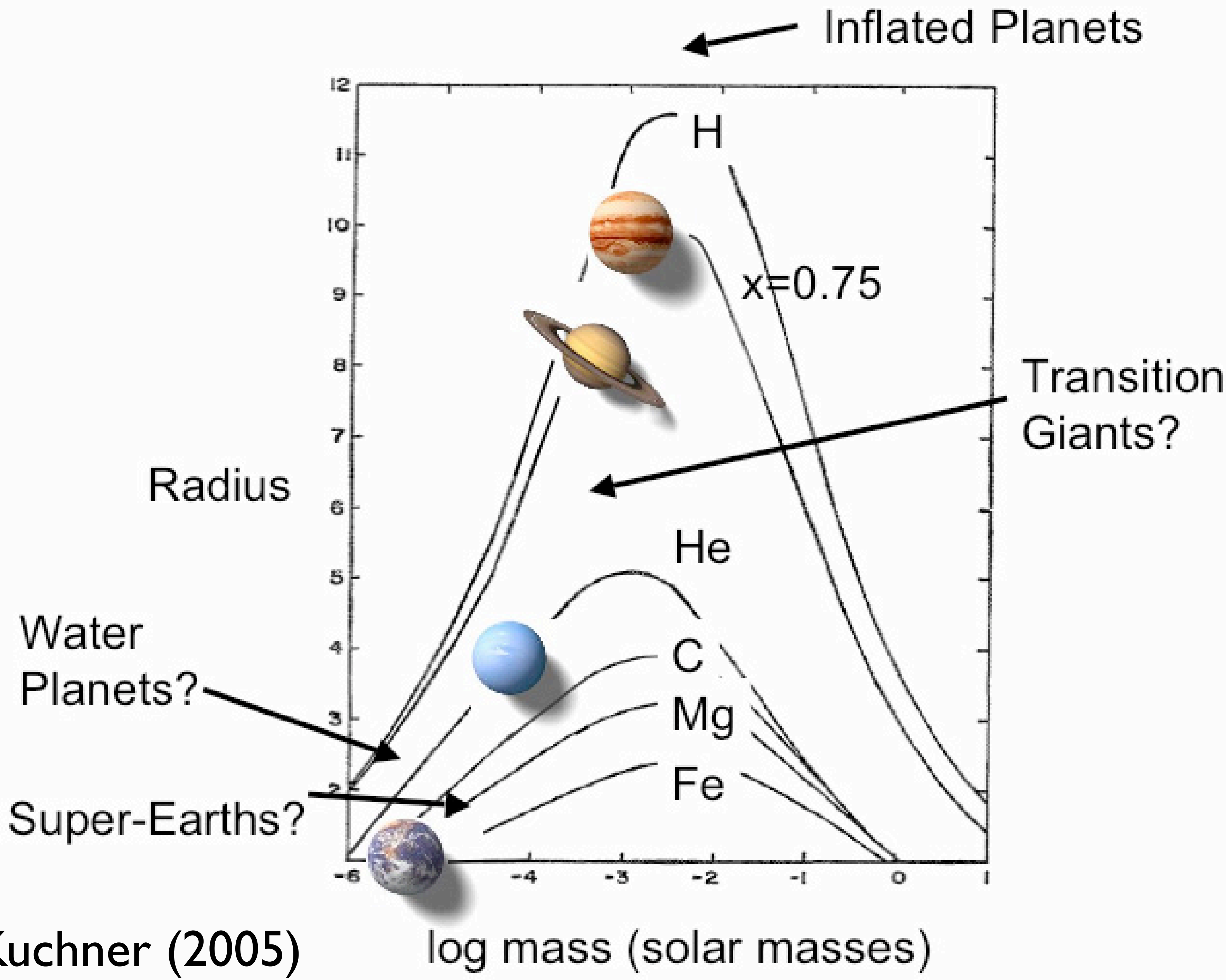
- Hot Jupiters have yielded far more interesting science than anyone ever imagined
- There will be a great diversity of worlds ("*There is more in heaven and Earth...*"); warm Neptunes to cold Jupiters -- mass alone does not characterize
- More prosaically...
  - Each planet costs ~$100,000+ to discover, we should capitalize on the investment
  - NASA routinely spends several hundred million (e.g., JUNO) to several billion (e.g., *Cassini*) **to study one planet**



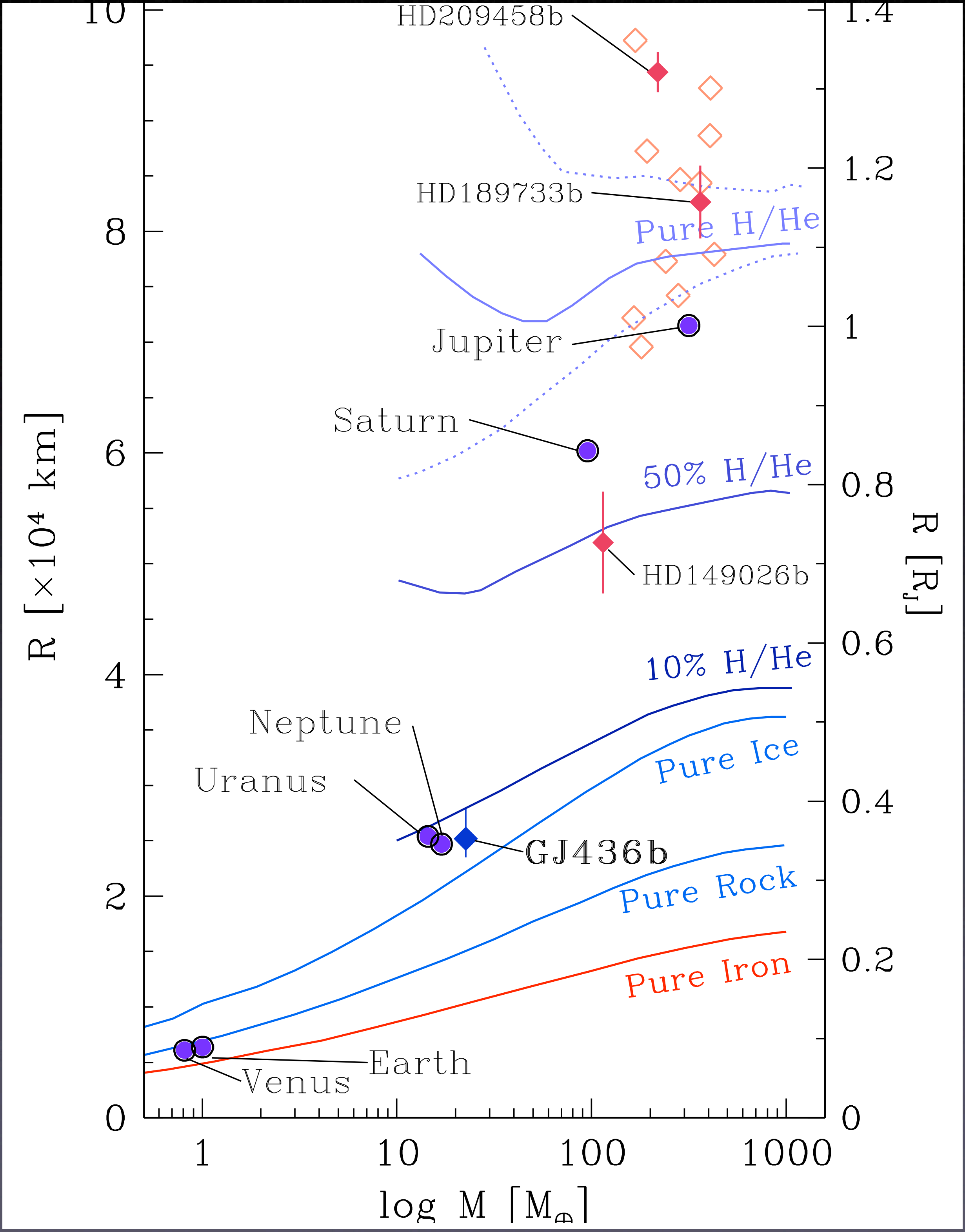
Characterization

- Mass - Easiest, but need to model how well a few coronagraphic images can resolve sin *i*
- Radius - Scattered light alone does not tightly constrain radius since albedo uncertain
  $R^2 a$





Kuchner (2005)



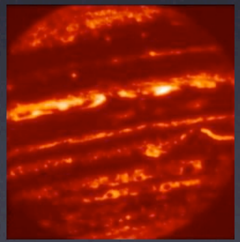
Gillon et al. (2007)

Synergy with IR

$$L = 4\pi R^2 \sigma T_{\mathrm{eff}}^4 = (1 - \Lambda)\pi R^2 (\pi \mathcal{F}_\star) + L_{\mathrm{int}}$$

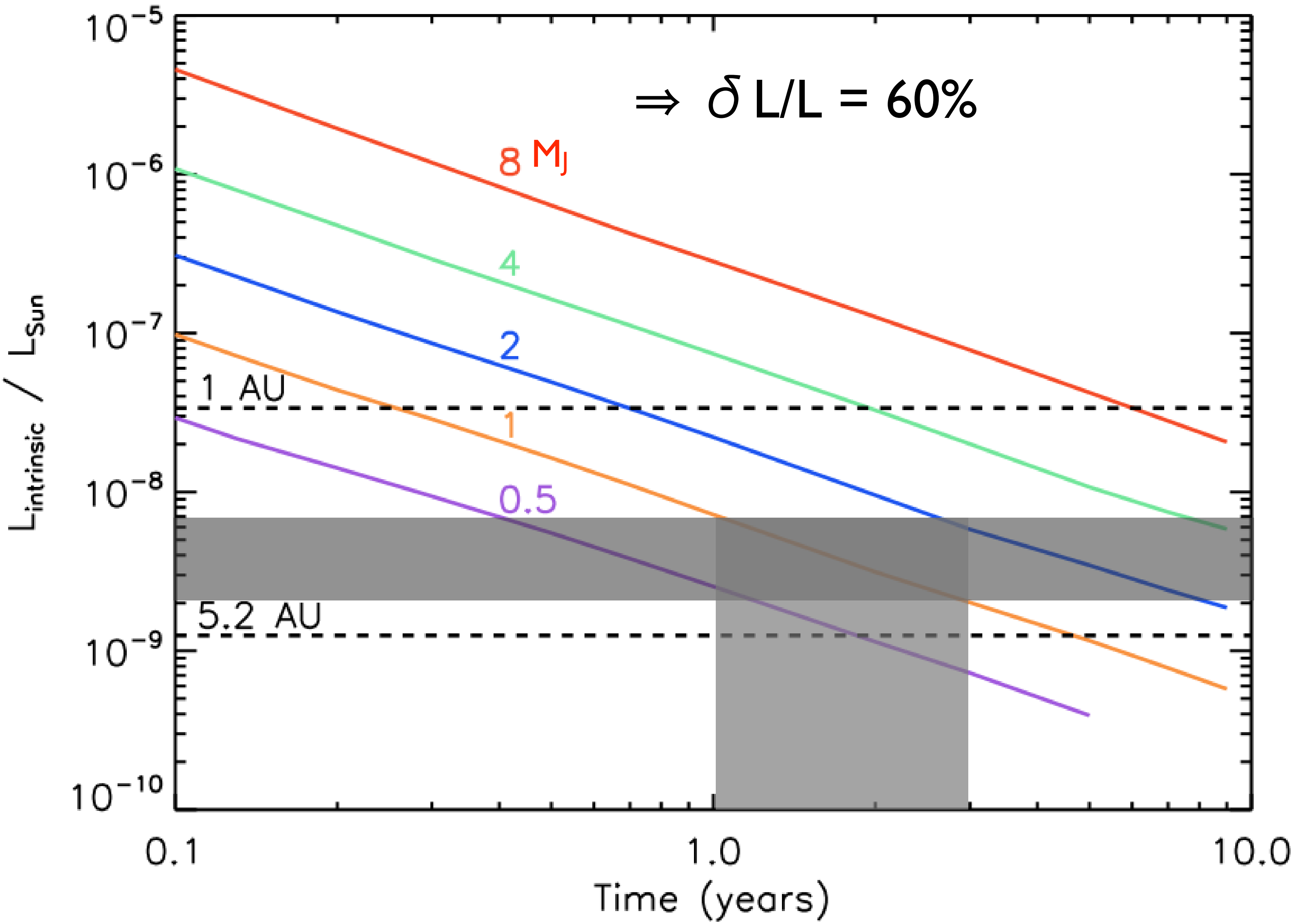
Mid-IR

Visible



R

$M = 1\ M_J$; age = 1 - 3 Gyr



Constraining *R*

$$L = 4\pi R^2 \sigma T_{\rm eff}^4 = (1 - \Lambda)\pi R^2 (\pi \mathcal{F}_\star) + L_{\rm int}$$

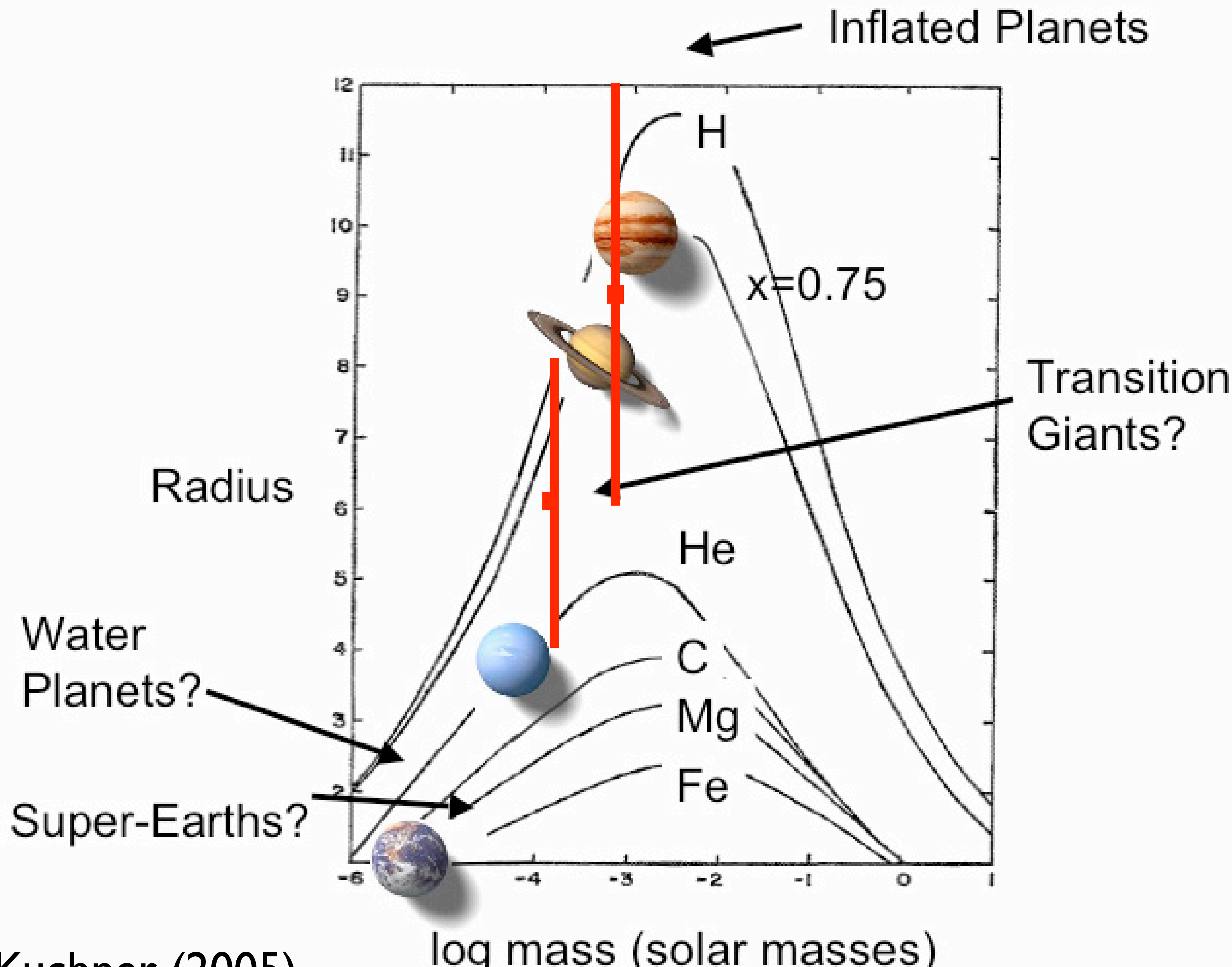
Mid-IR

Visible

R

$$\frac{\delta R}{R} > \frac{1}{2}\frac{\delta L_{\rm int}}{L}$$

easily 30% or more

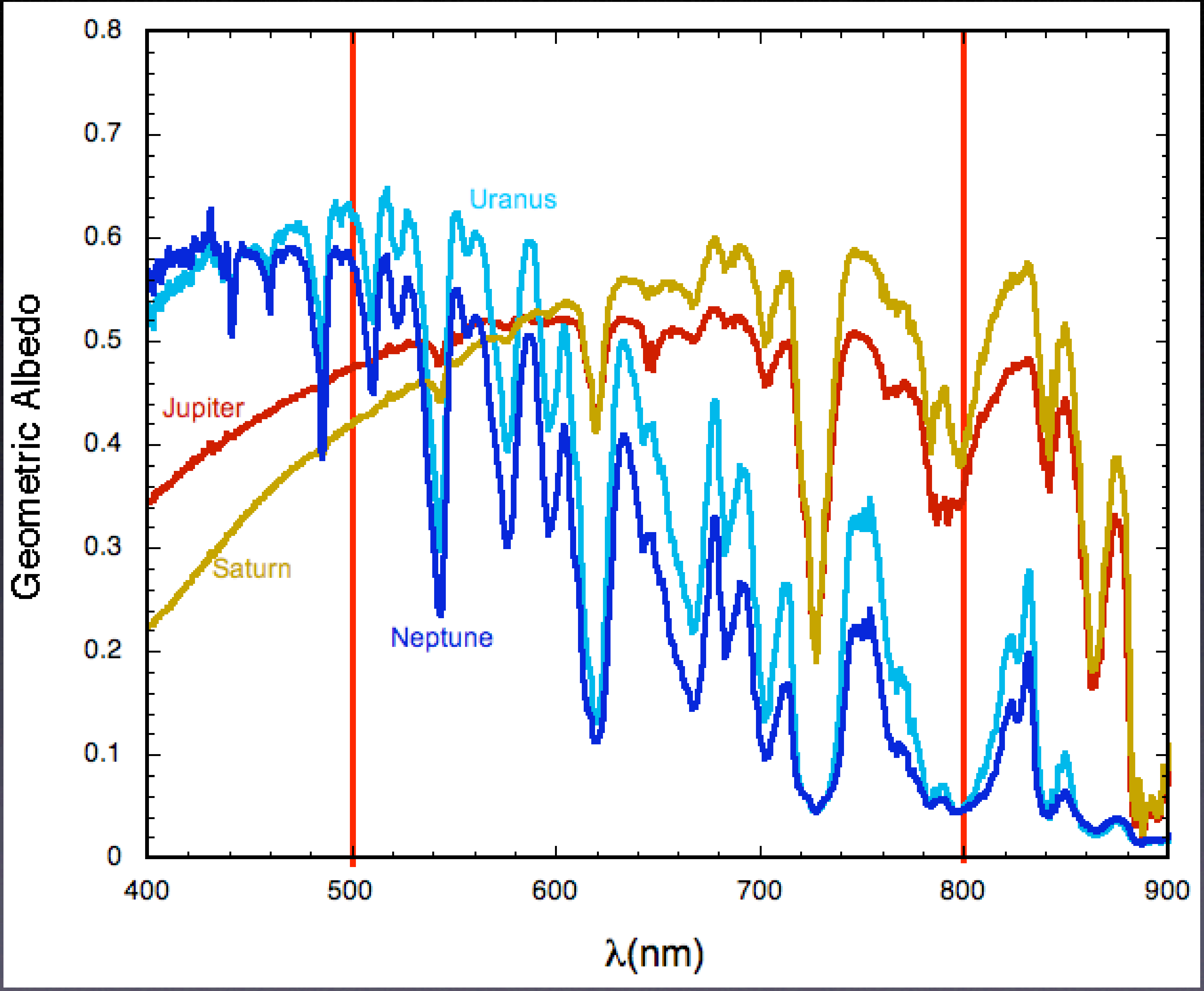


Kuchner (2005)

Conventional methods will not give accurate radii

Need Gravity Indicators

Spectra!

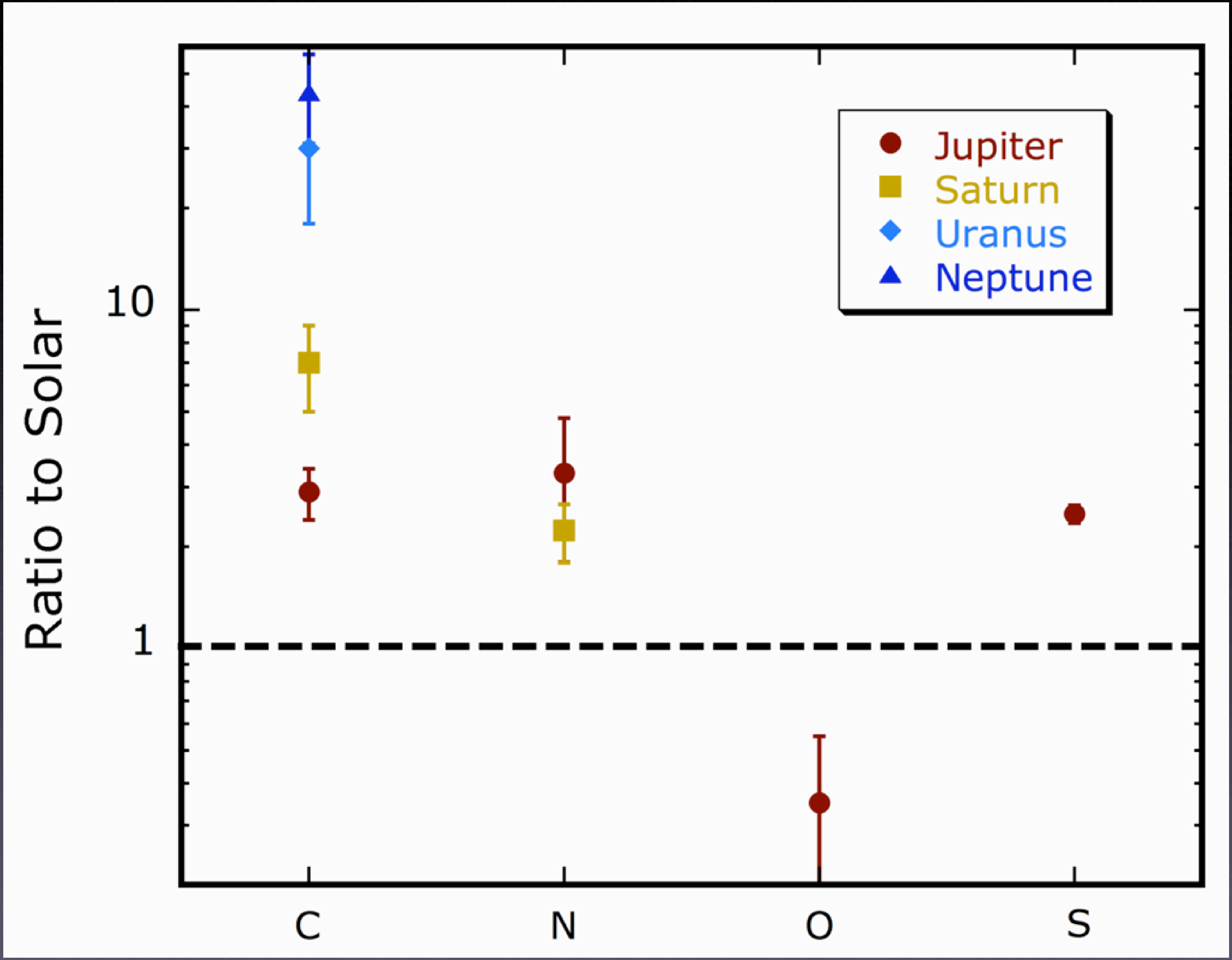

Geometric Albedo
λ(nm)
Uranus
Jupiter
Saturn
Neptune
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
400
500
600
700
800
900

Characterization

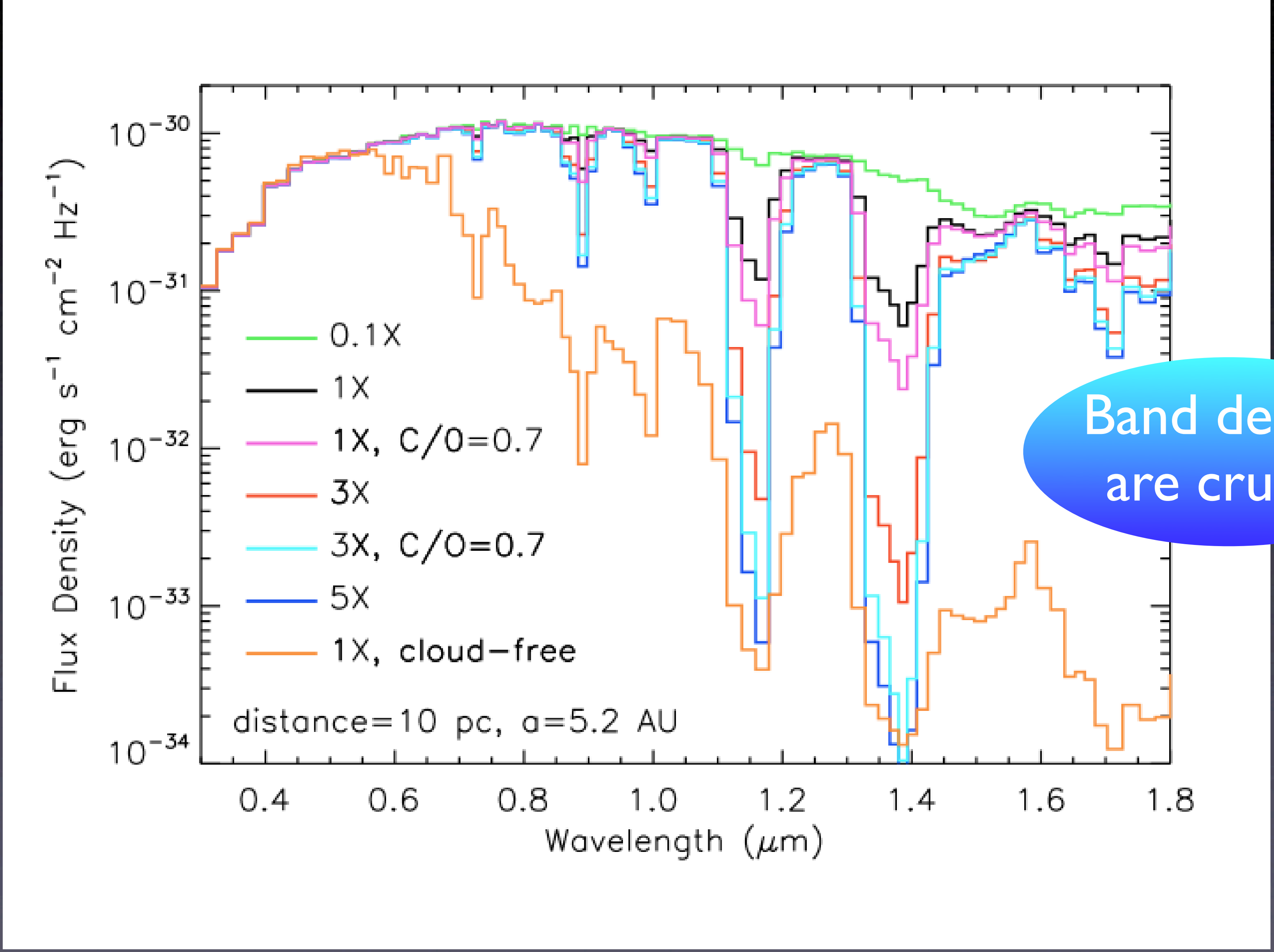
- Mass
- Radius
- Albedo
- Effective temperature
  - Equilibrium temperature
  - Internal luminosity

Characterization

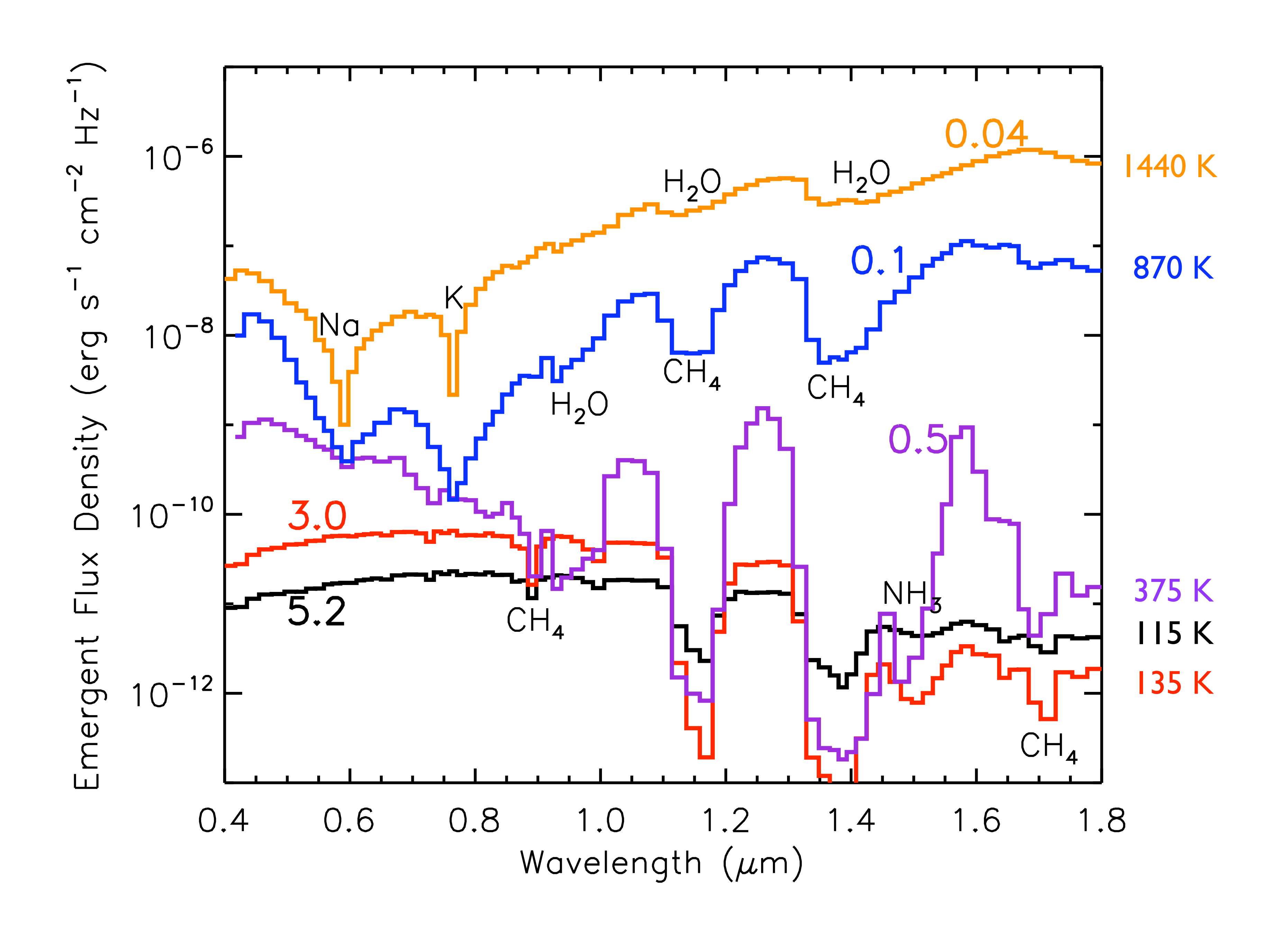
- Mass
- Radius
- Albedo
- Effective temperature
  - Equilibrium temperature
  - Internal luminosity
- ***Atmospheric Composition***


Ratio to Solar
10
1
C
N
O
S
Jupiter
Saturn
Uranus
Neptune

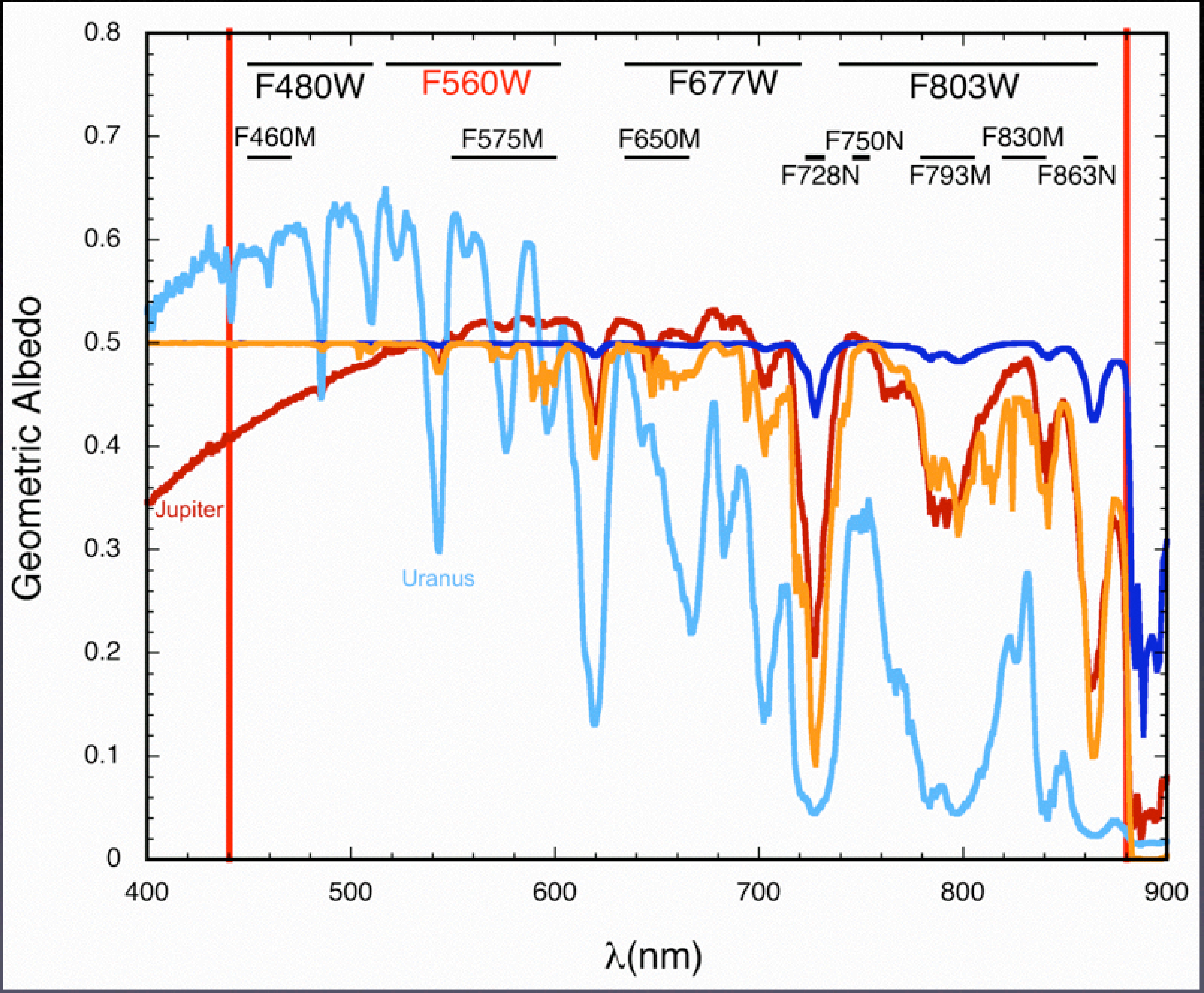
Composition Also Requires Spectra



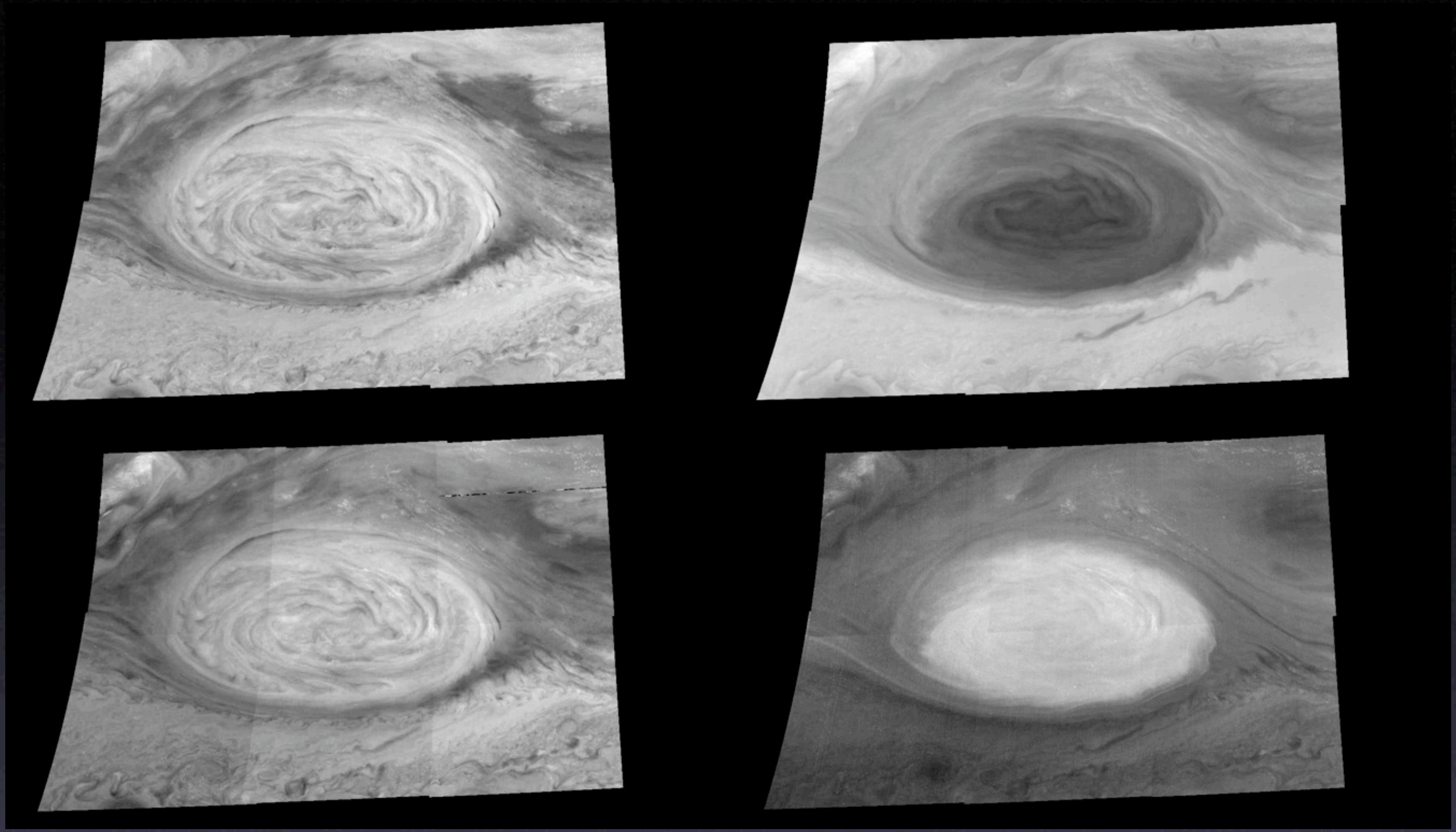
Band depths are crucial

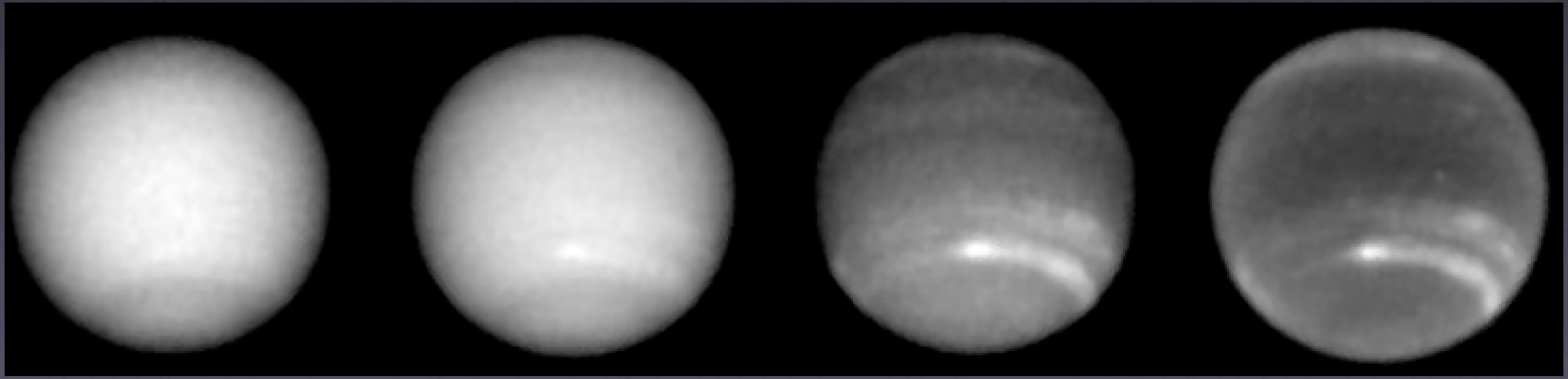


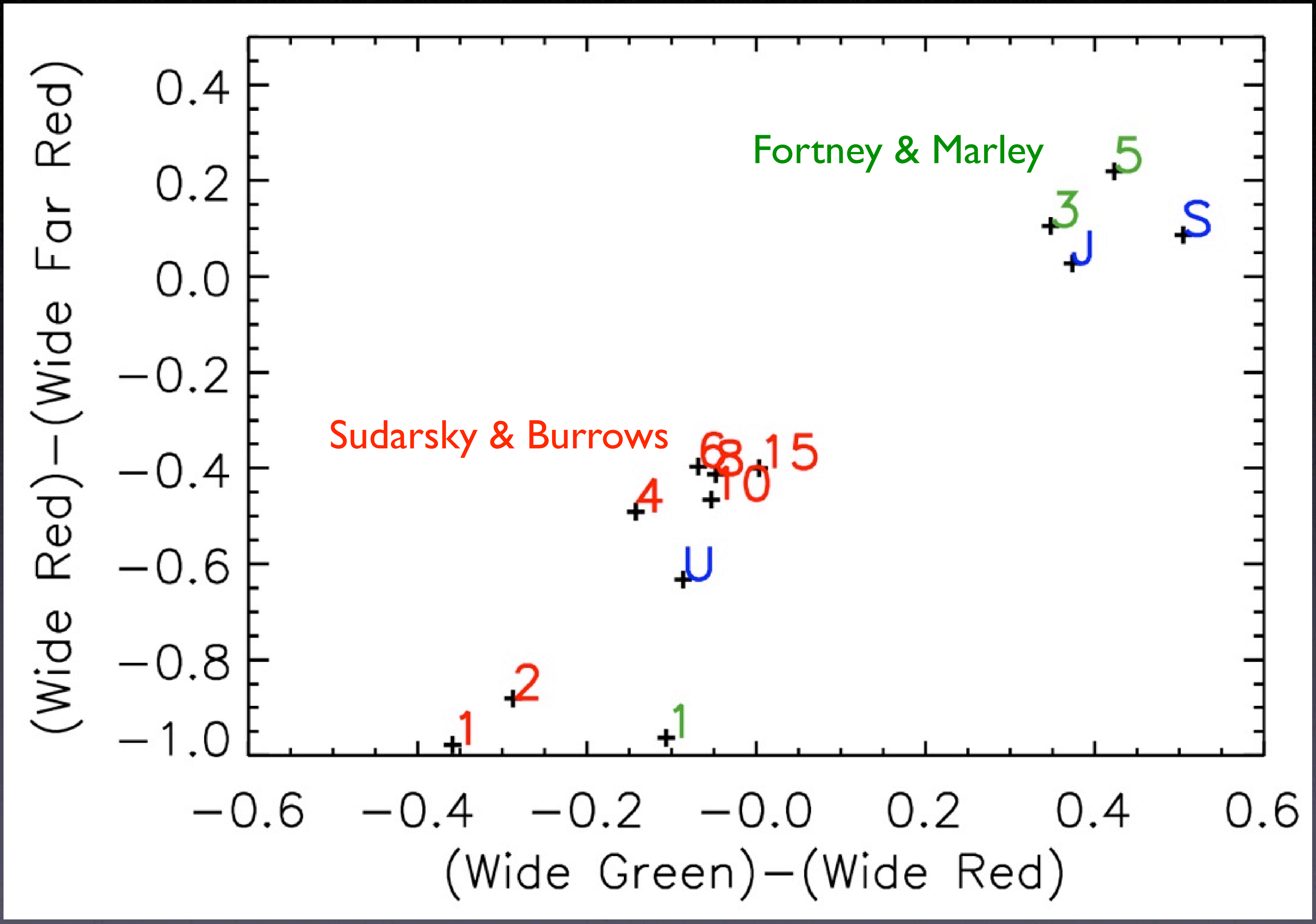
Fortney & Marley



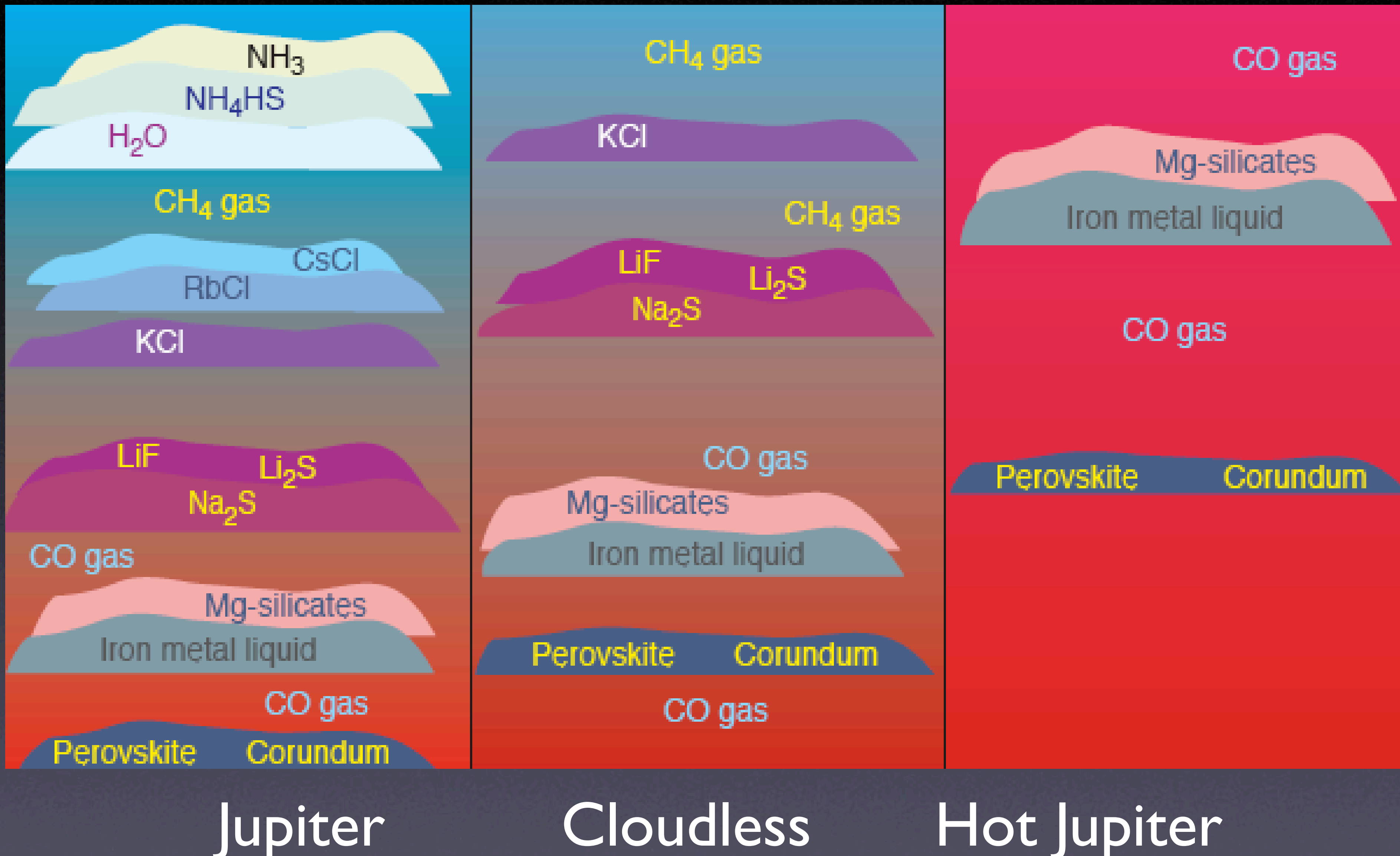
F480W
F560W
F677W
F803W
F460M
F575M
F650M
F750N
F830M
F728N
F793M
F863N
Jupiter
Uranus
Geometric Albedo
λ(nm)



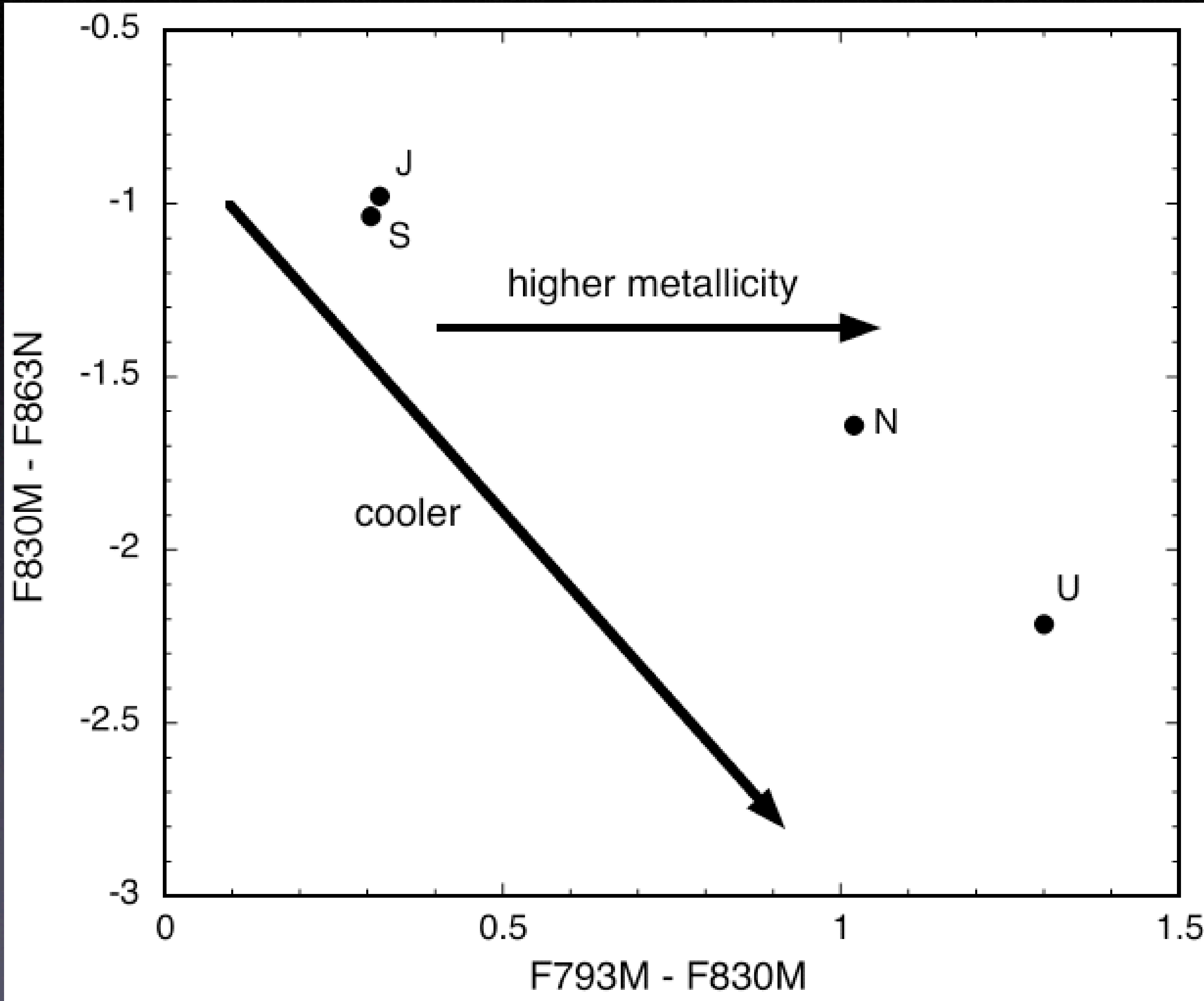




Fortney & Marley
Sudarsky & Burrows
5
3
S
J
6
8
15
10
4
U
2
1
1
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−0.6
−0.4
−0.2
−0.0
0.2
0.4
0.6
(Wide Red)−(Wide Far Red)
(Wide Green)−(Wide Red)



Lodders (2005)



-0.5
-1
-1.5
-2
-2.5
-3
0
0.5
1
1.5
F830M - F863N
F793M - F830M
J
S
N
U
higher metallicity
cooler

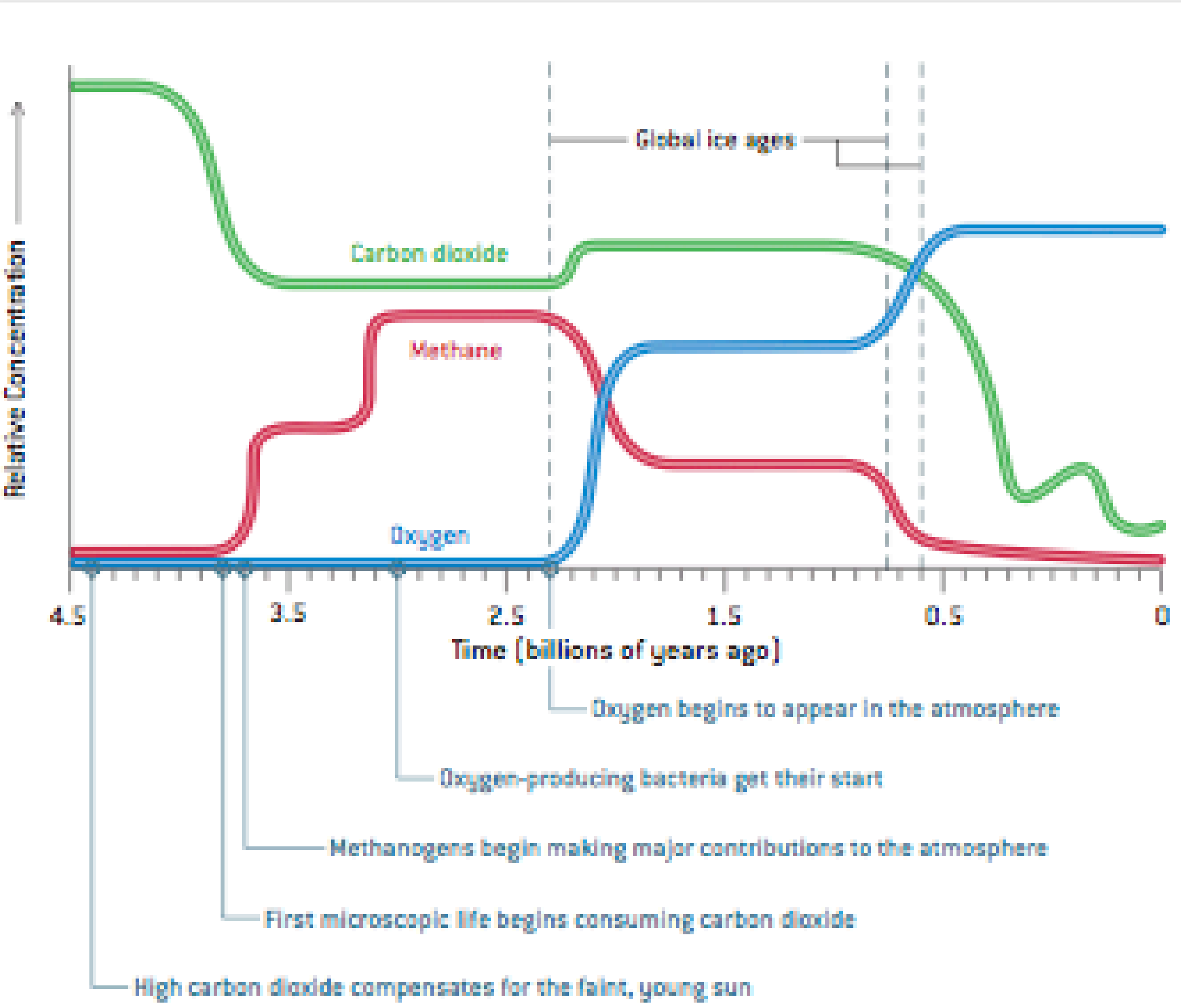
At Low Spectral Resolution

- Challenges
  - Clouds shape continuum
  - Hazes are a concern
- Can place constraints on
  - Composition
  - Gravity and hence radius
  - C/O
- Spectra are strongly prefered

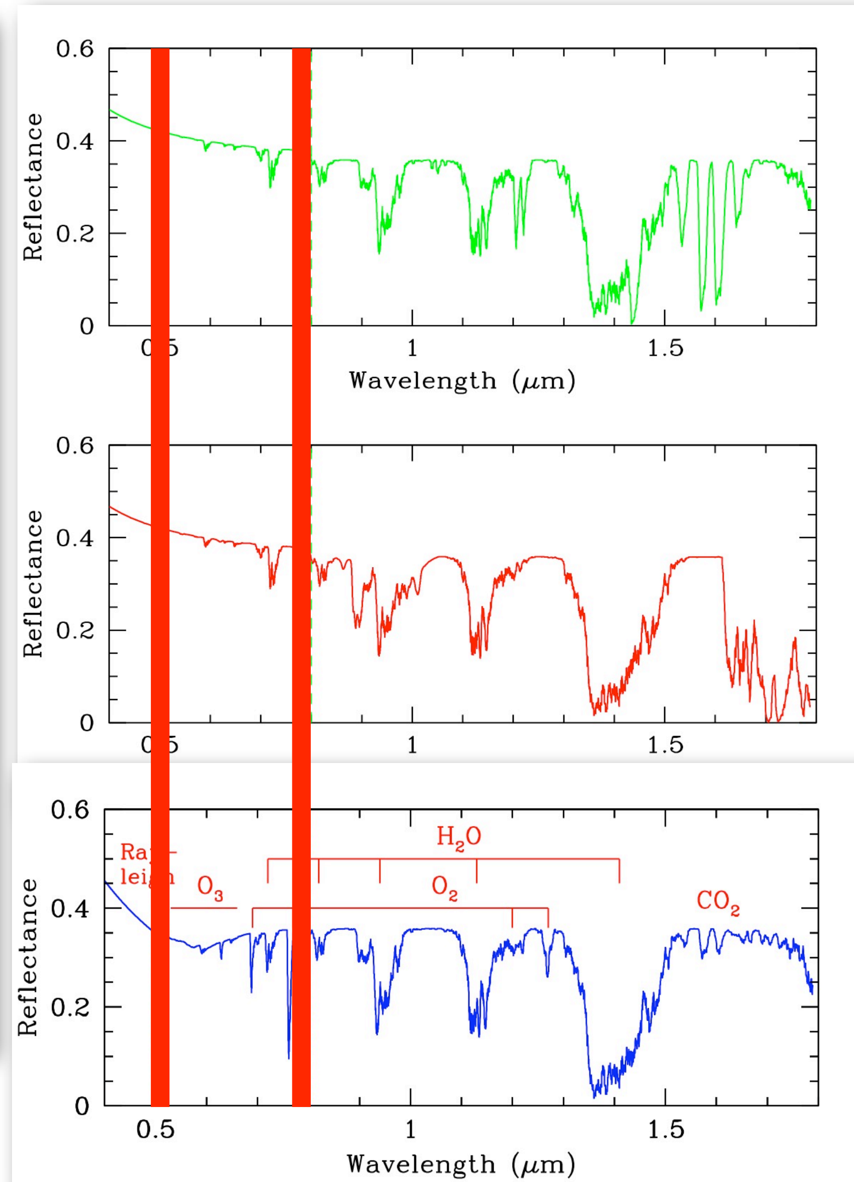
Terrestrial Planets

Characterizing Earths

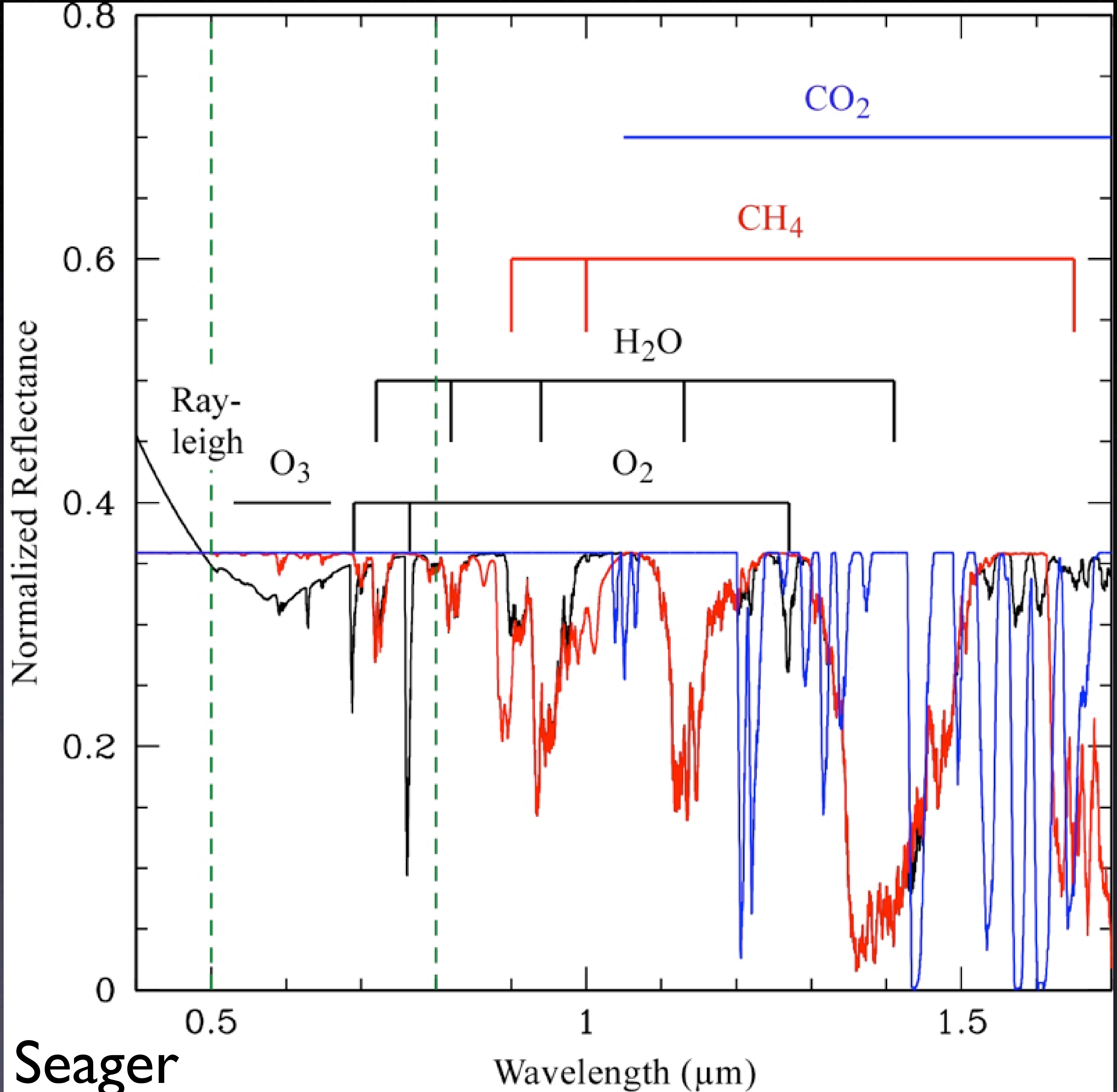
A Brief History of Earth's Atmosphere



Kasting (2004)

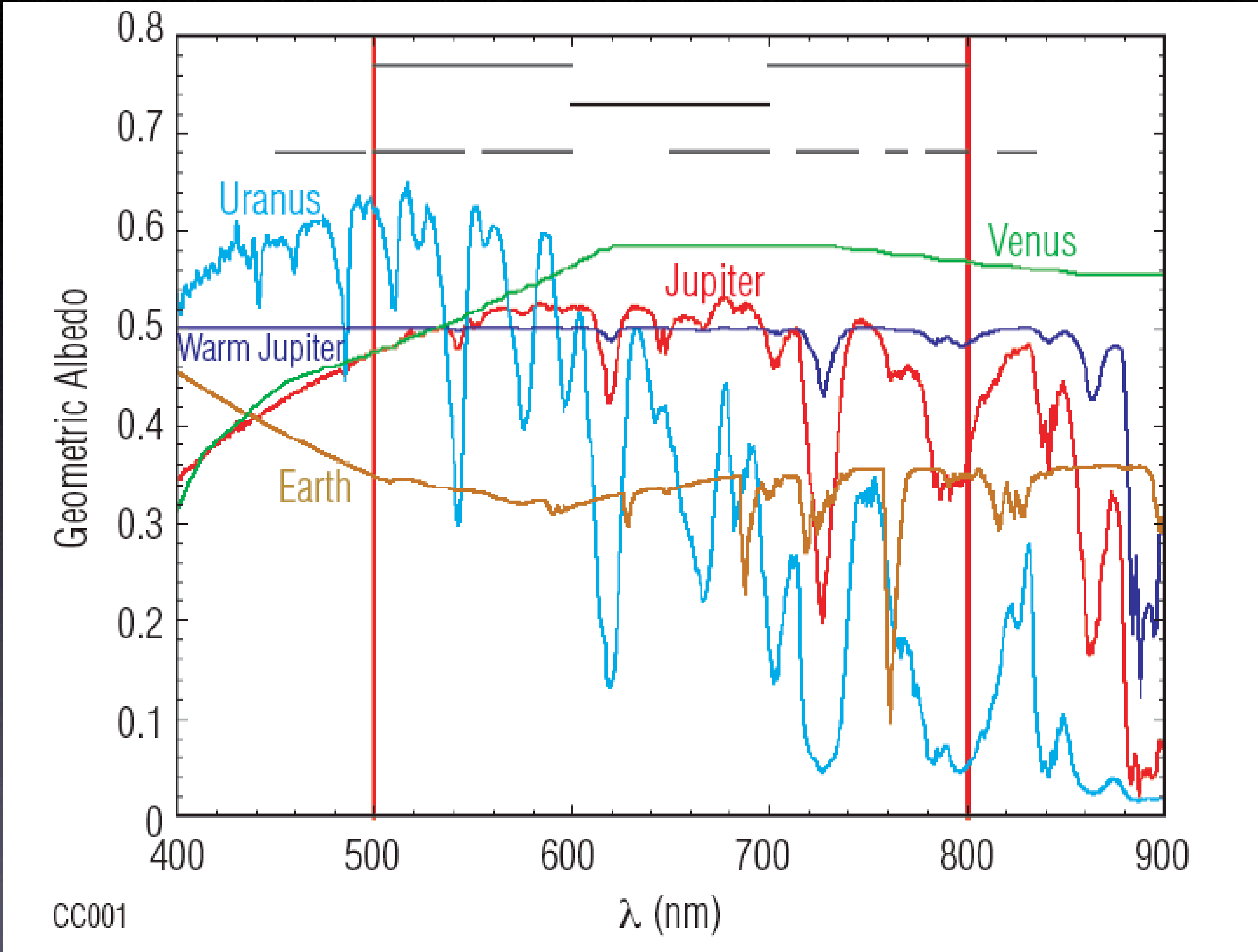


Seager (2004)



0.8
0.6
0.4
0.2
0
Normalized Reflectance
0.5
1
1.5
Wavelength (μm)
CO_2
CH_4
H_2O
Ray-
leigh
O_3
O_2

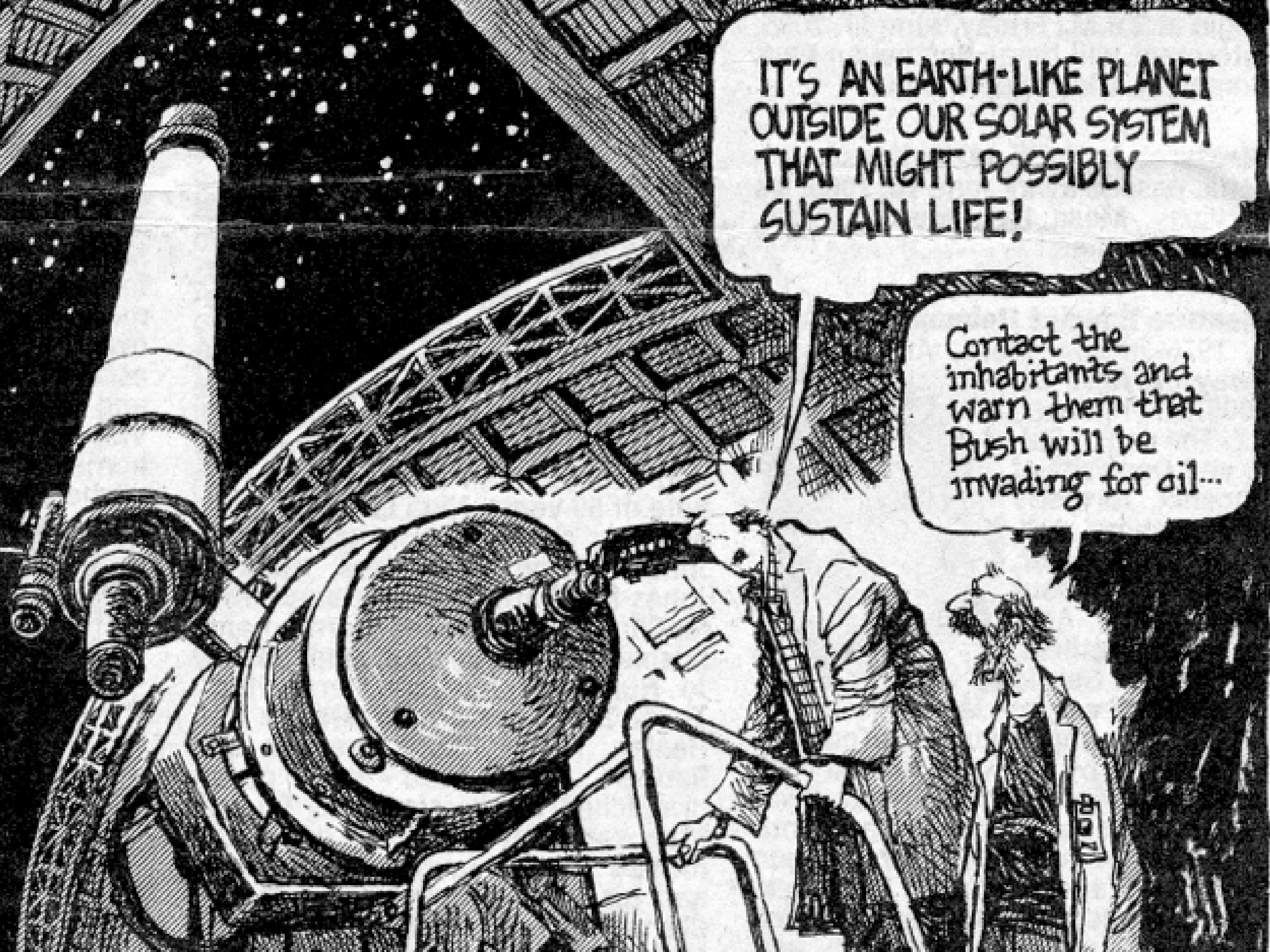
Seager



Geometric Albedo
λ (nm)
Uranus
Venus
Jupiter
Warm Jupiter
Earth
CC001
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
400
500
600
700
800
900

Terrestrials

- Hazes, clouds, etc. are also concerns
- Information is in band depths and spectral shapes
- Is it possible to get adequate S/N with modest sized telescope?


IT'S AN EARTH-LIKE PLANET OUTSIDE OUR SOLAR SYSTEM THAT MIGHT POSSIBLY SUSTAIN LIFE!
Contact the inhabitants and warn them that Bush will be invading for oil...